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USE OF INTENT INFORMATION IN AIRCRAFT CONFORMANCE MONITORING

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RESEARCH APPROACH

- **Main objectives of ATC: keep aircraft separated without unduly impeding traffic flows**

- **Knowledge of future behavior (intent) is fundamental to:**
  - ❑ Enable controller to establish a 'plan' to achieve these objectives
  - ❑ Determine whether this plan is being followed or not

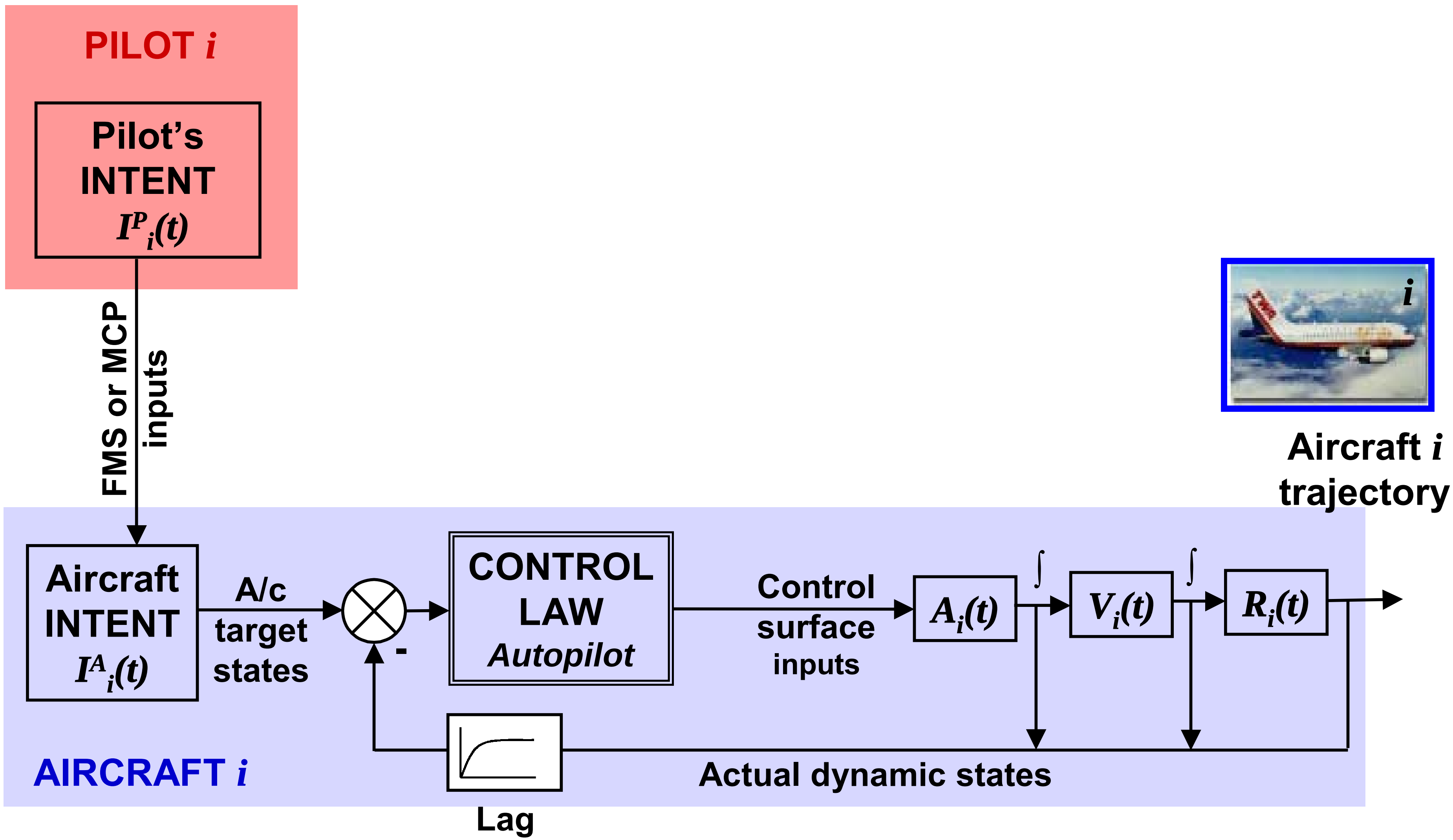
- **Define a state vector $X(t)$ containing:**
  - ❑ Current dynamic states
    - ➪ Position
    - ➪ Velocity
    - ➪ Acceleration
  - ❑ Higher order states representing future behavior
    - ➪ INTENT

‘TRUE’ & ‘SURVEILLANCE’ STATE VECTORS

$$\boldsymbol{X(t)} = \begin{Bmatrix} Position,\ R(t) \\ Velocity,\ V(t) \\ Acceleration,\ A(t) \\ Intent,\ I(t) \end{Bmatrix}$$

- $X_T(t)$ = ‘True’ state vector containing the actual aircraft states
- $X_S(t)$ = ‘Surveillance’ state vector used by controller containing measured or inferred aircraft states
- Only a subset of states may be directly surveilled in $X_S(t)$: controller infers others or controls without regard of those components

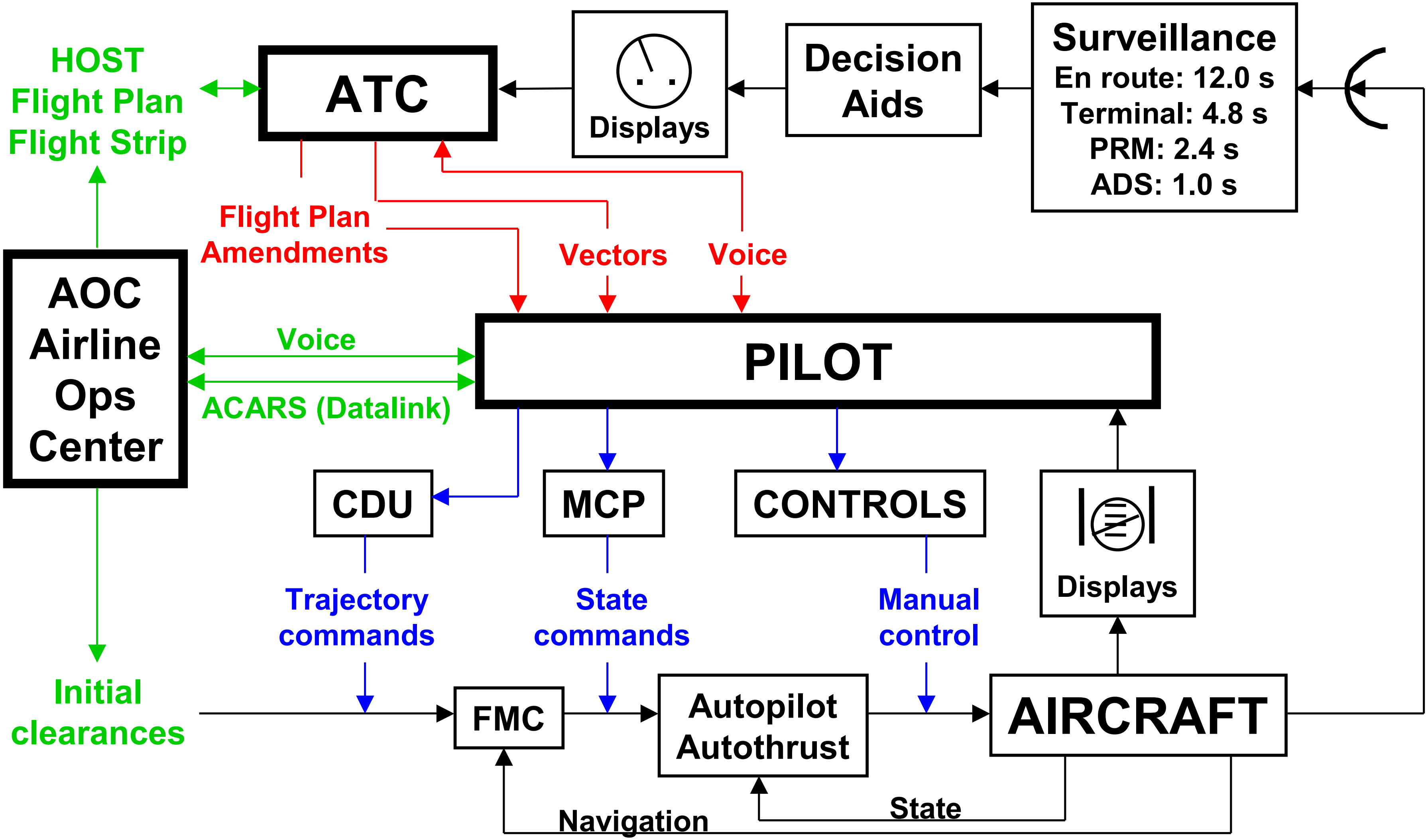
PILOT / AIRCRAFT INTERACTION



MOTIVATION FOR INTENT

- **Need for ‘surveilled intent’ representing the controller’s inference of the future behavior of aircraft in state space**
- **Inferring intent is logical extension to inferring lower order states (position, velocity, etc.)**
- **Intent not well defined in literature: need to tailor to this situation**
- **Approach taken defines intent based on formalism used in the operational ATC environment:**
  - Flight Plan
  - Clearances & vectors
  - Autopilot & FMS programming

ATM BASIC CONTROL LOOPS WITH INTENT FLOW



DEFINING INTENT

- **Working definition of intent:**
  - ❑ Future actions of aircraft which can be formally articulated & measured in the current ATC/flight automation system communication structure

$$\boldsymbol{I(t)} = \left\{ \begin{array}{c} \textit{Current target states} \\ \textit{4D planned trajectory} \\ \textit{Destination / Alternates} \end{array} \right\}$$

- **Aircraft is controlled to a set of ‘Current target states’ (e.g. airspeed, altitude, heading)**

- **Current target states are driven from the ‘4D planned trajectory’**

- **Planned trajectory driven by ‘Destination’**

INTENT CONSISTENCY BETWEEN ATC AGENTS

- **Define:**

  $I^G_i(t)$ = intent for aircraft i as programmed into the ground automation system (e.g. HOST Computer System)

  $I^C_i(t)$ = controller's intent for aircraft i

  $I^P_i(t)$ = pilot i's intent for his/her aircraft

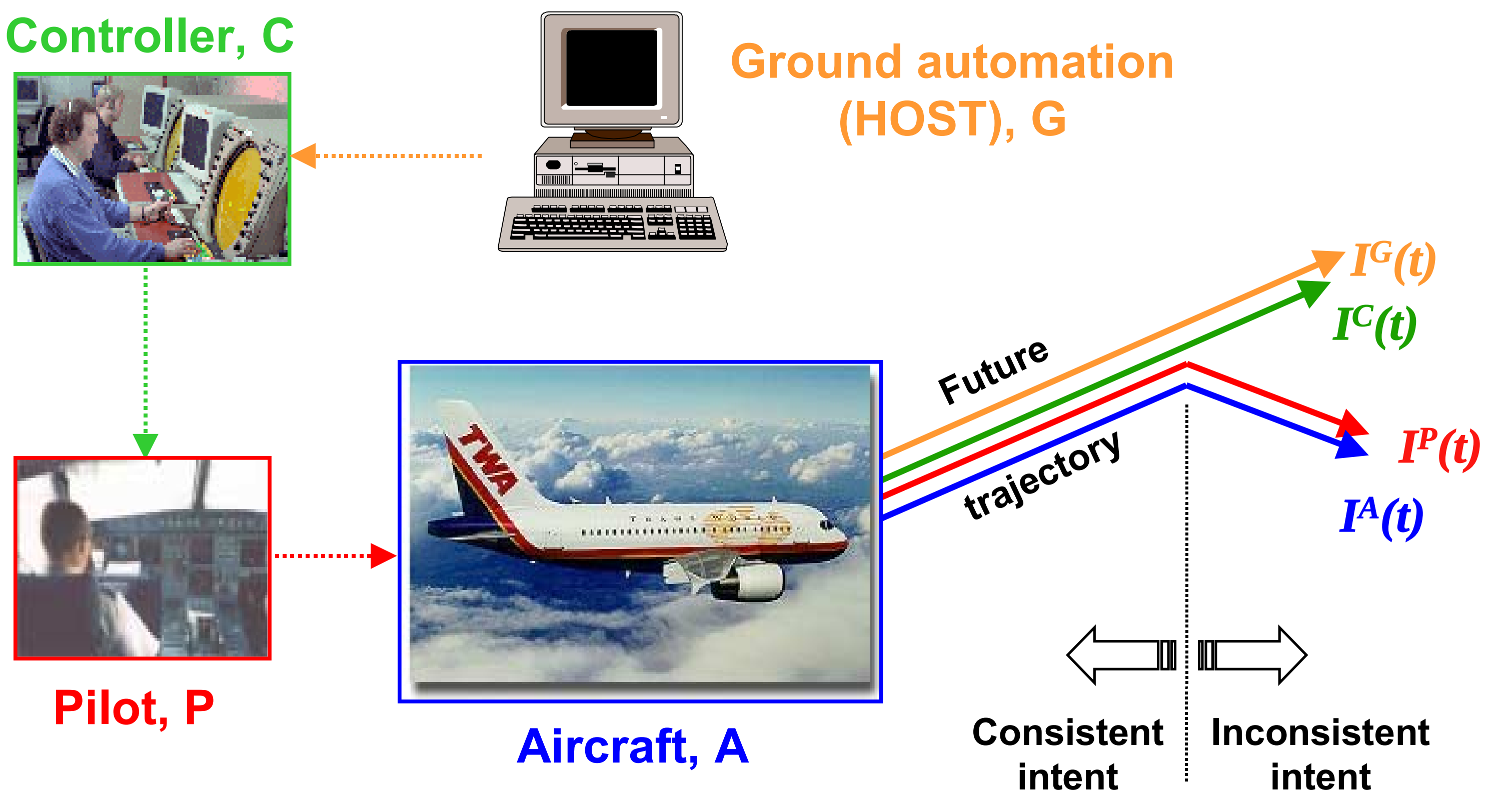
  $I^A_i(t)$ = intent for aircraft i as programmed into the autoflight system

- **$I^G_i(t) = I^C_i(t) = I^P_i(t) = I^A_i(t)$ for consistent intents for aircraft i**

- **Inconsistencies in intent between system agents (e.g. controller, pilot & aircraft/ground automation) may lead to the development of a hazardous situation**

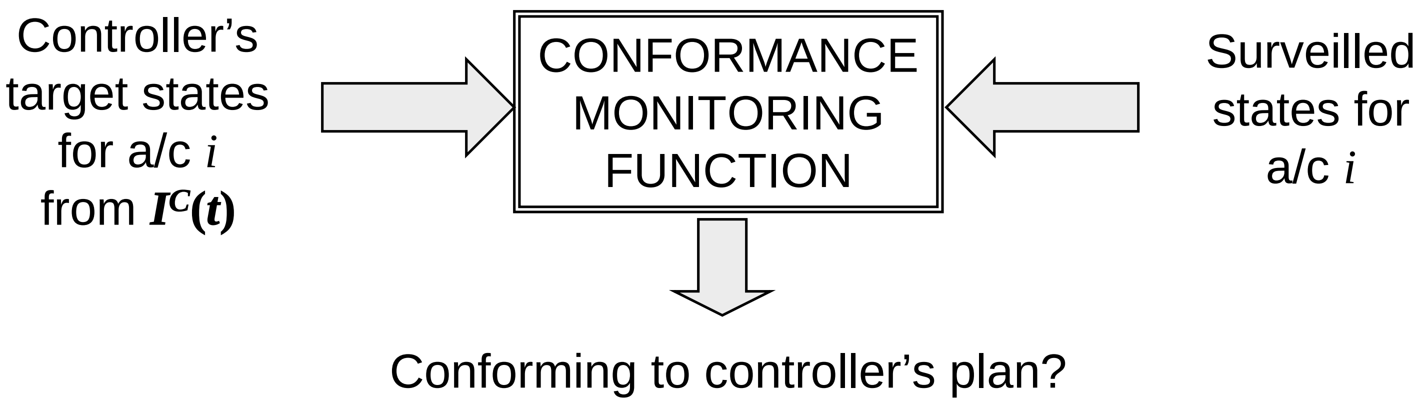
EXAMPLES OF INTENT INCONSISTENCY BETWEEN ATC AGENTS

- Pilot misunderstands clearance, $I^G(t) = I^C(t) \neq I^P(t) = I^A(t)$
- Autoflight system omission/programming error, $I^G(t) = I^C(t) = I^P(t) \neq I^A(t)$
- Host Computer System not updated, $I^G(t) \neq I^C(t) = I^P(t) = I^A(t)$



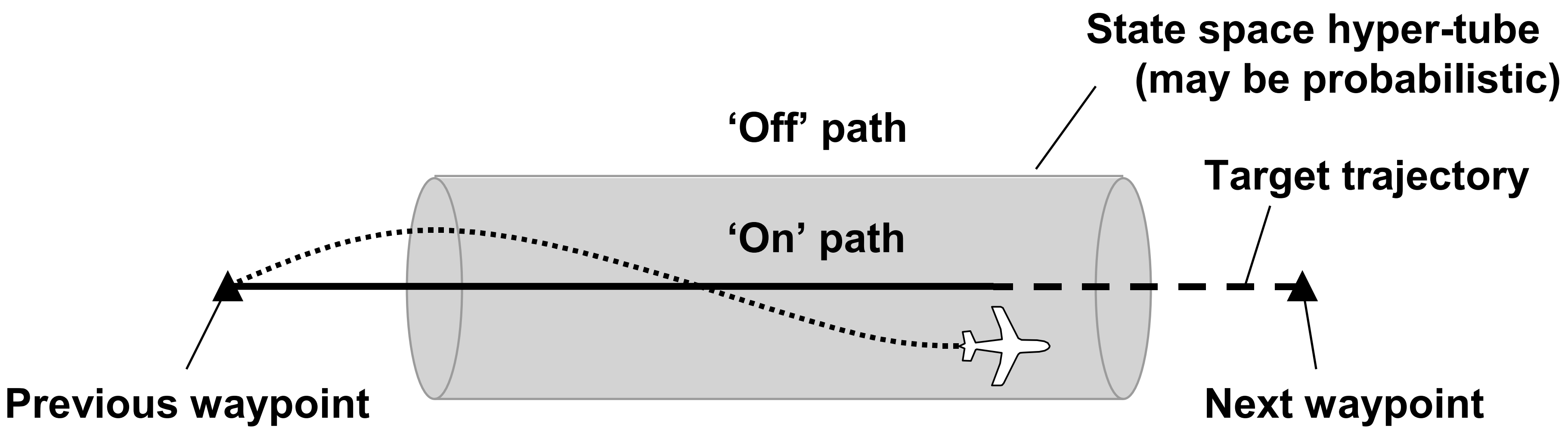
HOW *X(t)* COMPONENTS ARE USED BY ATC

- **Based on preliminary field observations, controller seems to develop a ‘plan’ for their sector based on:**
  - ❑ Current position of each aircraft
  - ❑ Future position based on velocity and heading
  - ❑ Future behavior based on knowledge/inference of intent (if available)
- **Monitors CONFORMANCE TO THE PLAN once established to determine if aircraft are adhering to presumed intent or whether any corrective action is required**



CONFORMANCE MONITORING

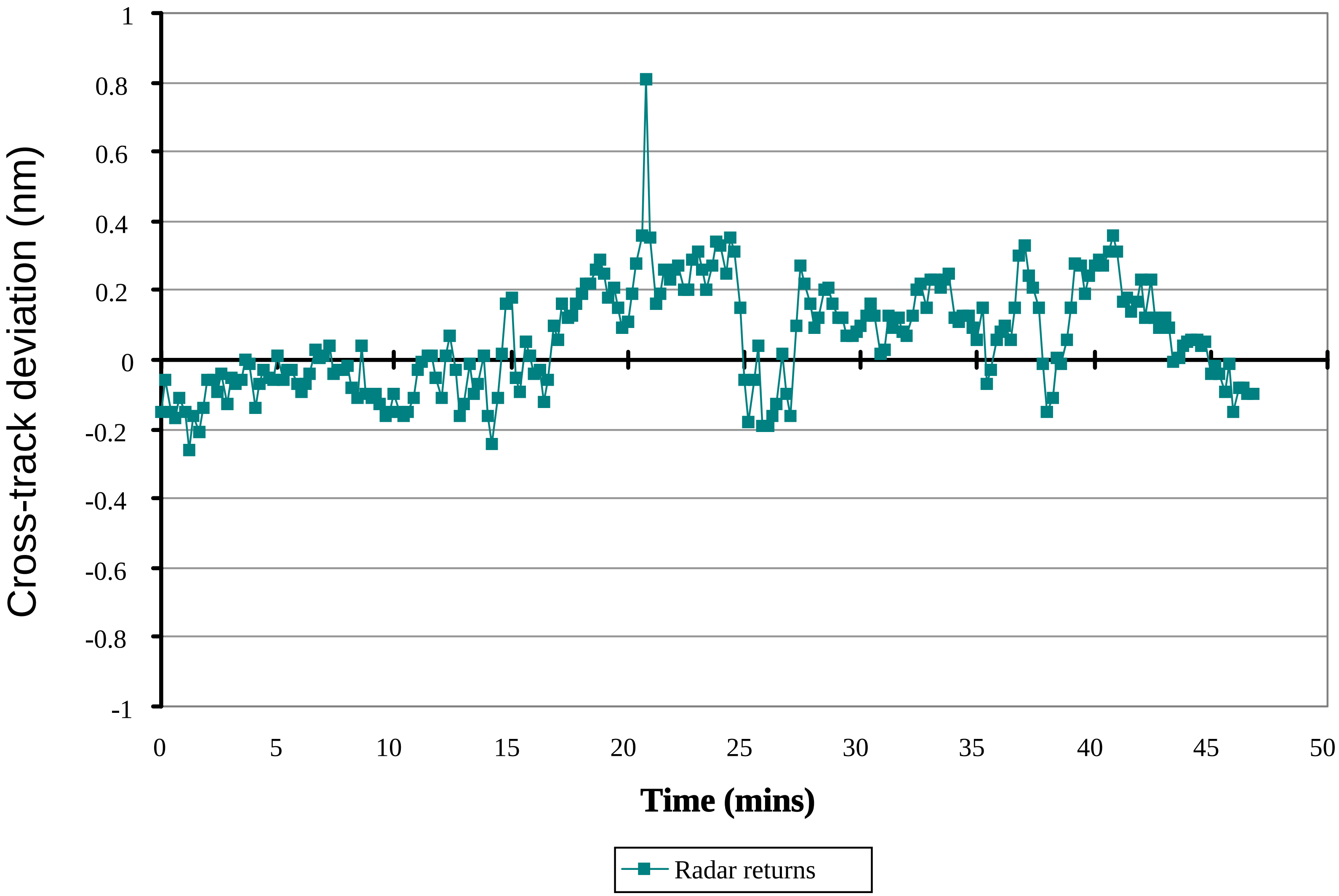
- Controller compares surveillance data to internal representation of control system (pilot or autopilot), aircraft dynamics and measurement system performance
- Hypothesis testing of whether aircraft is adhering to intended or cleared path:



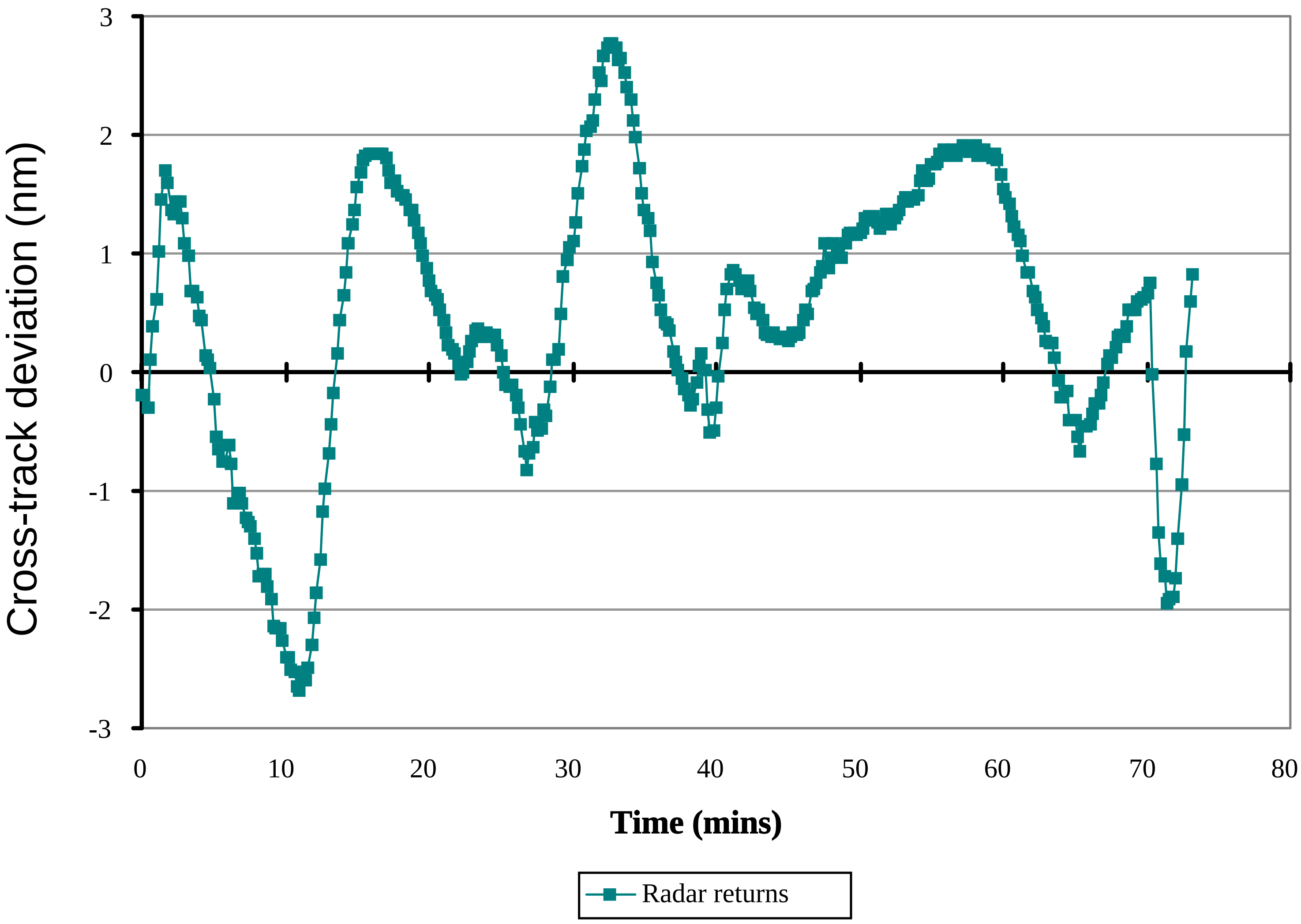
FACTORS IMPACTING CONFORMANCE CAPABILITY

- **Several hours of ZME HOST computer system data analyzed**
- **Important factors affecting conformance capability:**
  - ❑ Aircraft navigation equipage level
    - ➪ FMS
    - ➪ INS
    - ➪ VOR/DME
    - ➪ None of the above
  - ❑ Flight mode
    - ➪ Autopilot
    - ➪ Heading
    - ➪ Manual
  - ❑ Speed
  - ❑ Altitude
  - ❑ Maneuver
  - ❑ Location wrt navaids
  - ❑ Pilot experience

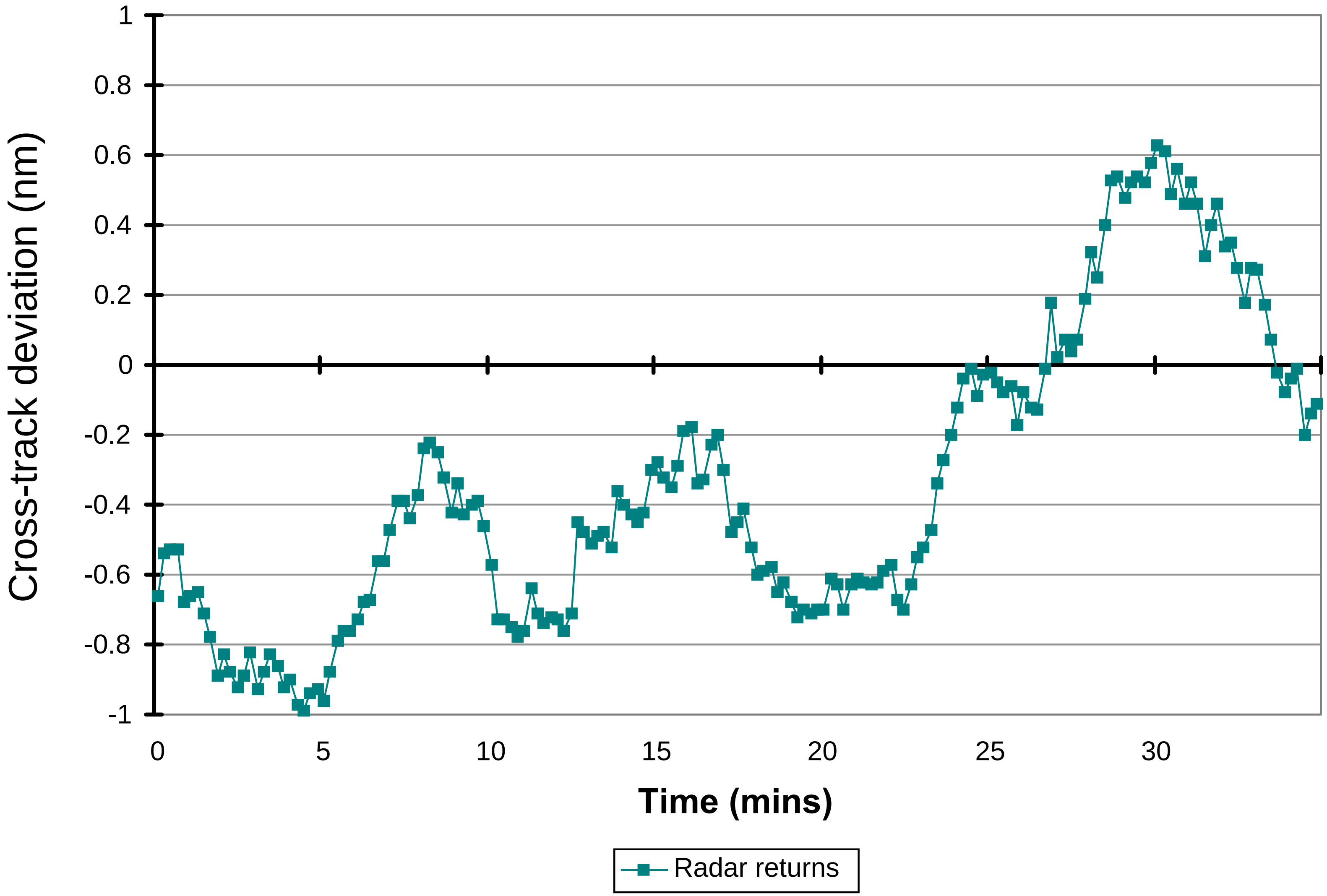
TYPICAL FMS TRACKING BEHAVIOR (A320)



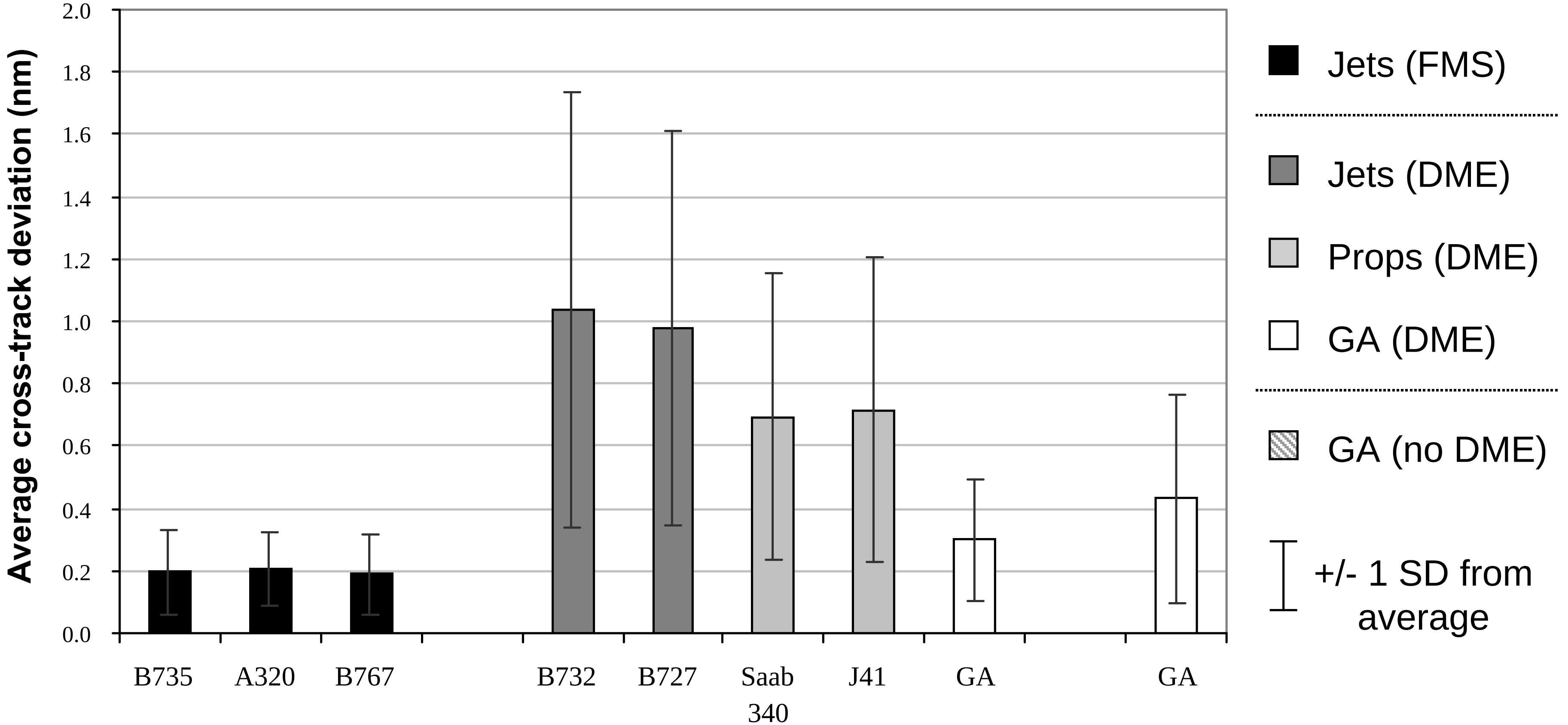
TYPICAL VOR/DME TRACKING BEHAVIOR (B732)



TYPICAL UNEQUIPPED TRACKING BEHAVIOR (Cessna 172)



TRACKING VARIABILITY WITH A/C TYPE & EQUIPAGE



- Raw data: ZME host computer, 5/26/99 (courtesy Mike Paglione, FAA Tech Center)
- Cross track deviations measured when established on track
- Minimum of 5 hrs of data per type

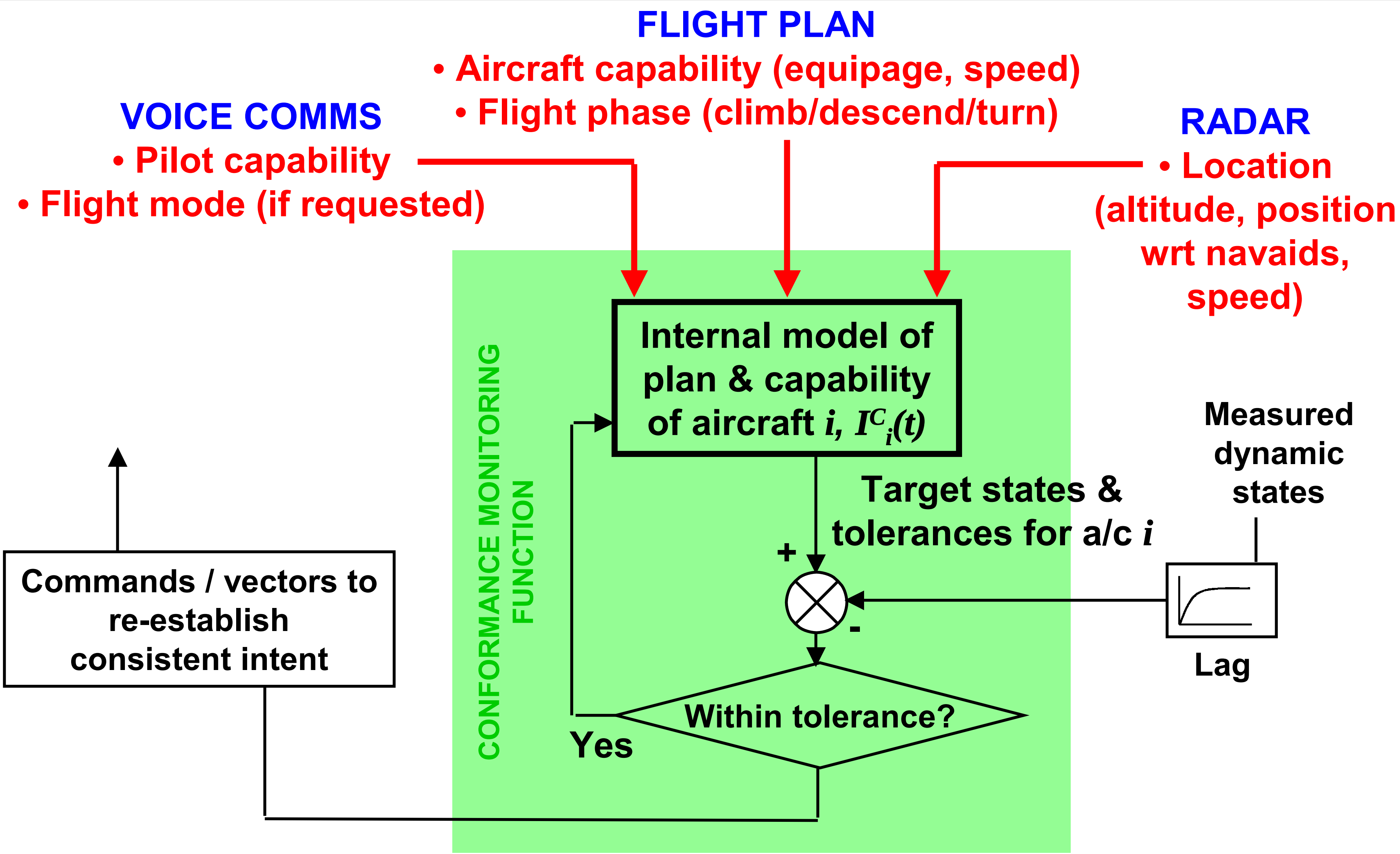
AIRCRAFT TYPE ALTITUDE & SPEED COMPARISON

- Typical cruise characteristics:

Type	Altitude	Speed
Jets	> 30,000 ft	400 – 500 kts
Props	10,000 – 25,000 ft	200 – 300 kts
GA	< 10,000 ft	100 – 200 kts

- Higher altitude = larger error using angular navaids (VOR/DME)
- Higher speed = larger deviation off path in a given amount of time for similar control systems

CONFORMANCE MONITORING AS HYPOTHESIS TESTING: ON OR OFF INTENDED PATH

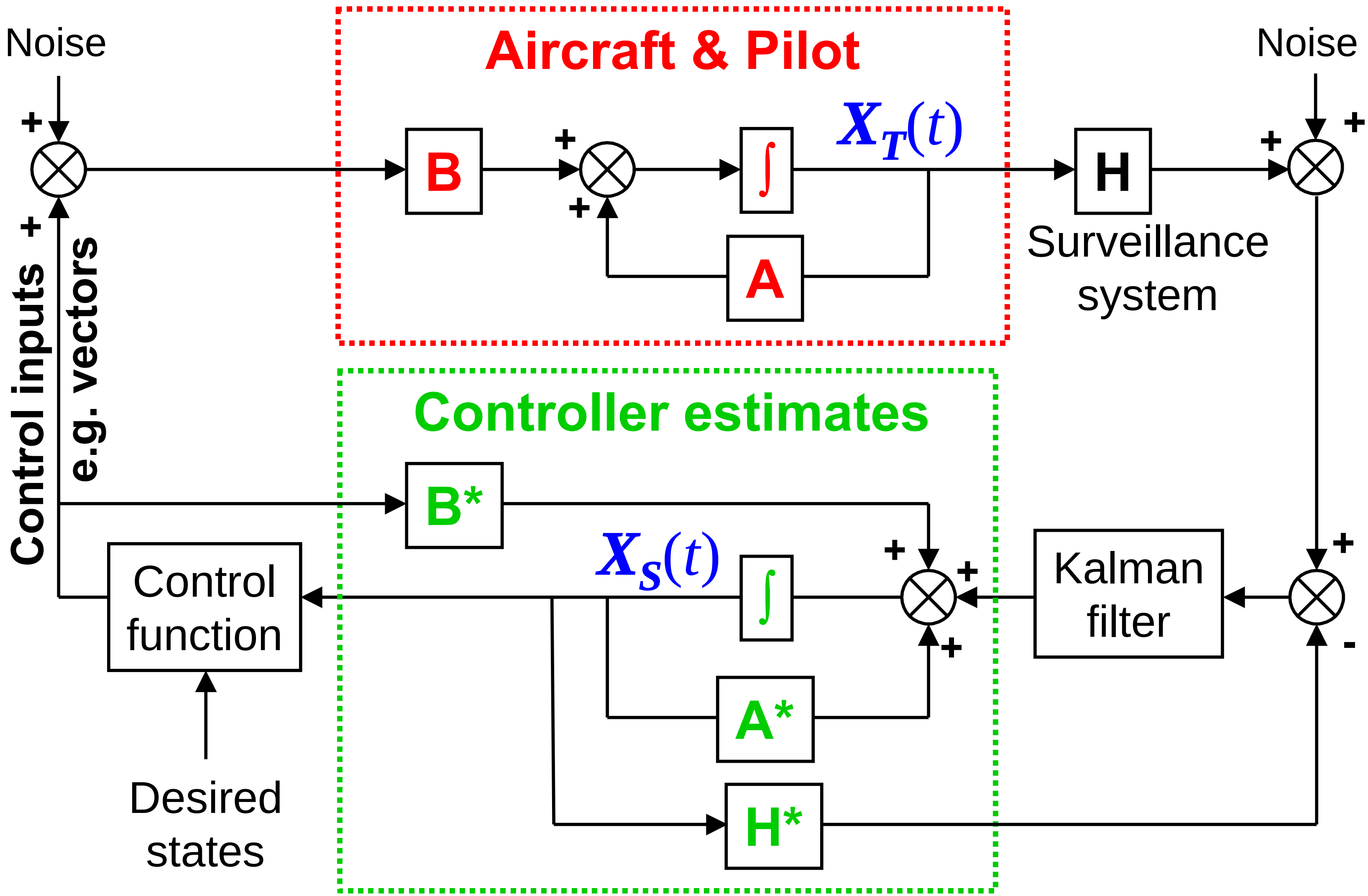


CONCLUSIONS

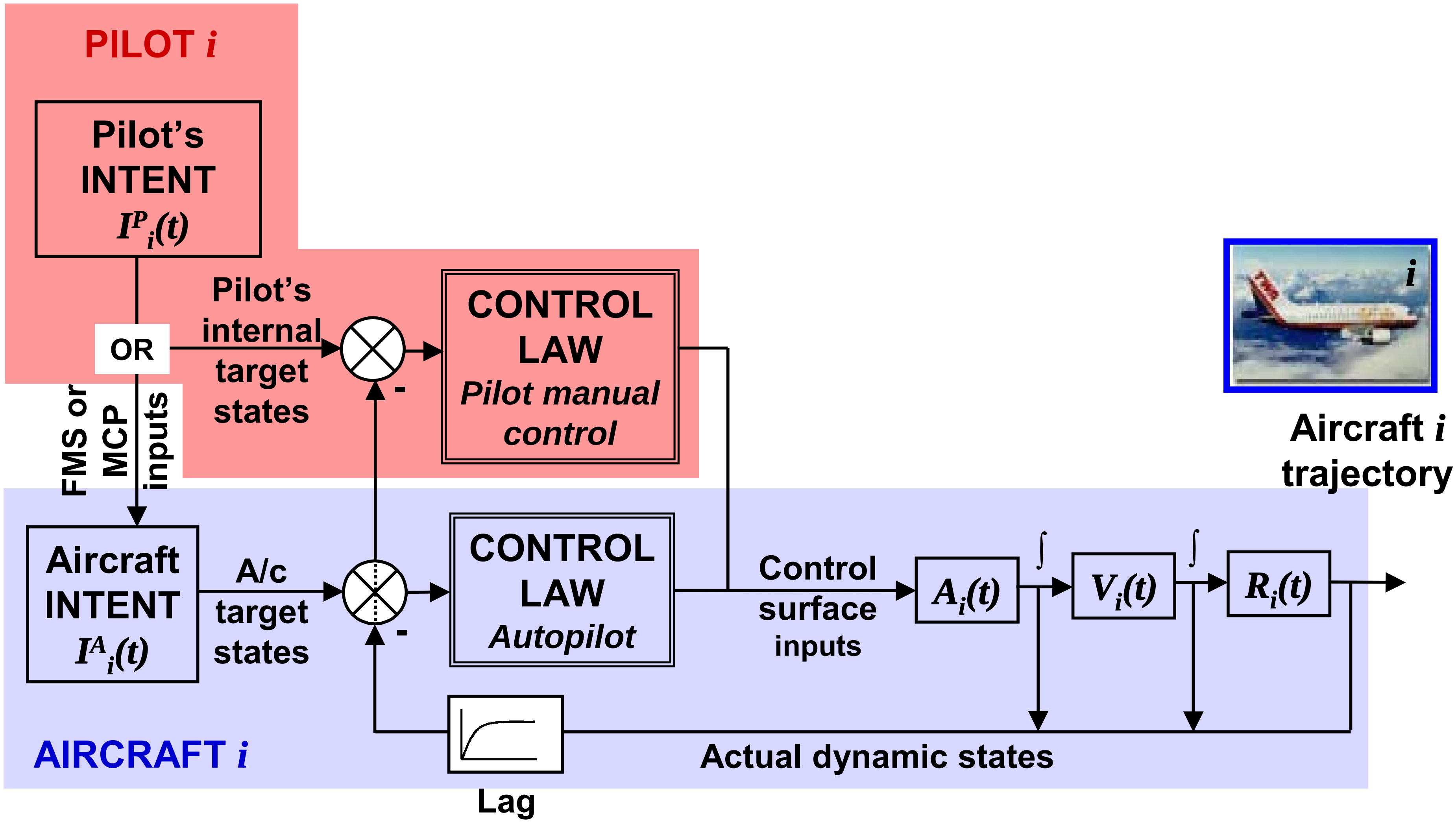
- **Surveillance state vector combines traditional dynamic states of position, velocity & acceleration with higher order intent states**
- **Intent states are essential for projecting dynamic states into future, enabling controller to formulate a plan for the behavior of the aircraft in the sector**
  - ❑ Maintain safe separation
  - ❑ Manage flow efficiently
- **Current controller knowledge of intent is implicit & noisy**
- **Conformance monitoring task establishes how well intent is being followed and whether controller intervention is required**
- **Benefit of explicit intent to be investigated**
  - ❑ Datalink
  - ❑ Procedures

BACKUP SLIDES

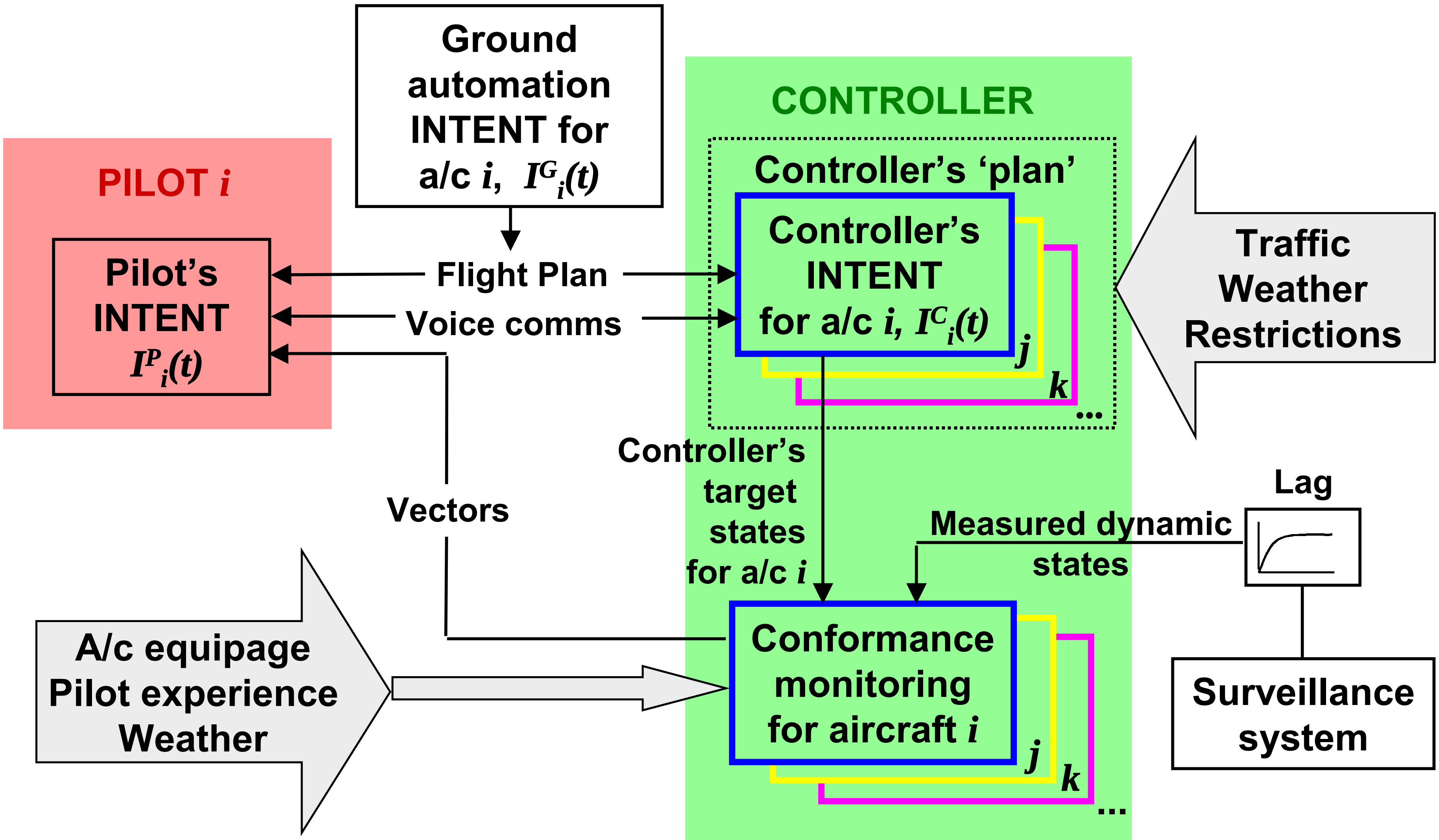
CONTROL THEORY ANALOGY



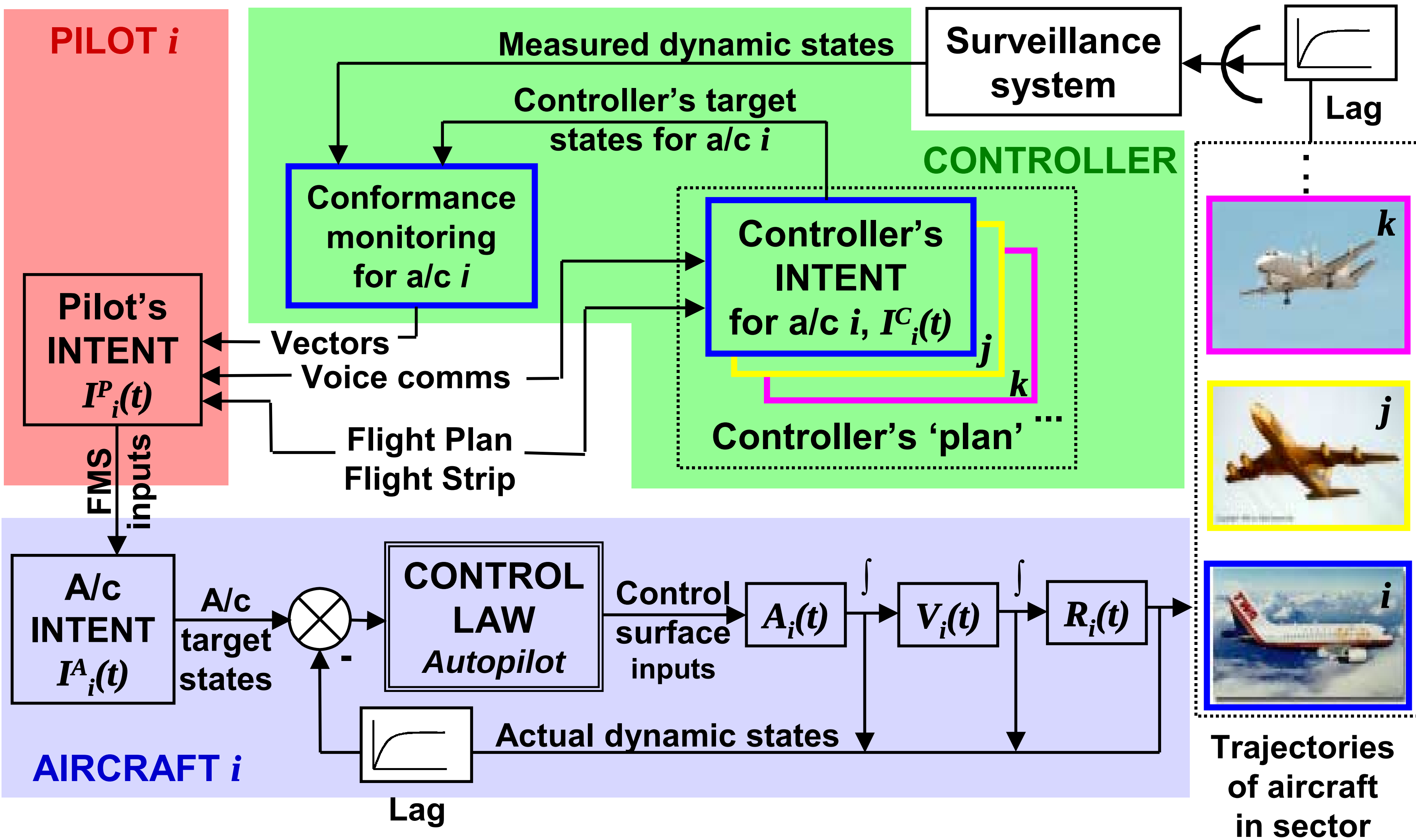
PILOT / AIRCRAFT INTERACTION



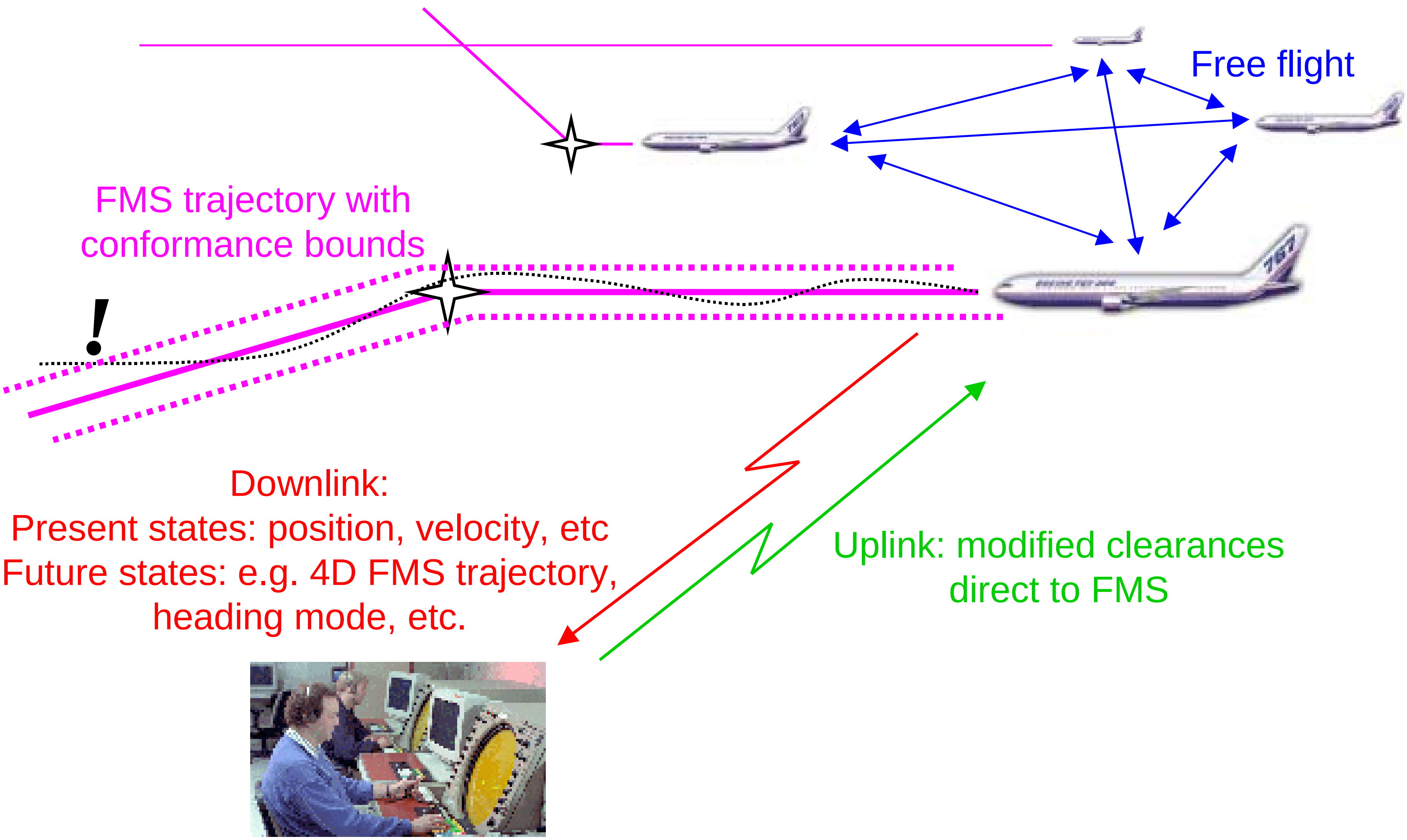
PILOT / CONTROLLER INTERACTION



CONTROLLER / PILOT / AIRCRAFT INTERACTION LOOP



EXAMPLE USES OF INTENT



FUTURE WORK

- **Implications for ADS-B content**
- **Basis for new conflict detection algorithms**
- **New paradigm for issuing control clearances**
- **Analyze benefits of making more intent information available to the controller:**
  - ❑ Could controller use/send other information from/to the aircraft to better understand/communicate intent
    - ➪ Downlink of autopilot flight mode?
    - ➪ Automated conformance monitoring systems
    - ➪ Datalink direct from/to FMS?